Relationship between tectonic zones of the Albanides, based on results of geophysical studies

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ABSTRACT

The Albanides link the Dinarides and the Hellenides, with which they form the southern branch of the Mediterranean Alpine Belt. Our analysis of the Albanides and their extension into the Adriatic Sea integrates surface geological observations, well data and results of seismological, refraction- and reflection-seismic, gravity, magnetic and geoelectric surveys.

The evolution of the Albanides began with the Triassic subsidence of their Hercynian substratum under a tensional regime, culminating in crustal separation and opening of the Subpelagonian and Hellenic-Dinarid oceanic basins. The Alpine orogenic history of the Albanides spans Late Jurassic to Quaternary times and can be subdivided into a Late Jurassic-Early Cretaceous early-tectonic, a Mid-Cretaceous to Eocene main-tectonic, an Oligocene-Miocene late-tectonic and a Plio-Pleistocene neo-tectonic cycle.

The Albanides consist of two major palaeogeographic domains. The Internal Albanides formed part of the oceanic Subpelagonian Trough, whereas the External Albanides developed out of the western passive margin and continental shelf of the Adriatic plate. During the early-tectonic phase, the ophiolitic Mirdita nappe was obducted onto the margin of the Adriatic plate. This was accompanied by the development of a flexural foreland basin. During the main-, late- and neo-tectonic phases, progressive westward advance of the orogenic front was coupled with a westward shift of the foredeep basin axis to its present location at the margin of the Adriatic Sea. The External Albanides evolved out of the Ionian Mesozoic shelf sedimentary prism and the superimposed foredeep wedge. The Albanides are underlain by autochthonous continental basement which was little deformed during their evolution.

The ophiolites of the Mirdita nappe give rise to major gravity and magnetic anomalies, indicating that its thickness ranges between 2 and 14 km. Reflection-seismic and gravity surveys carried out in the External Albanides and the Adriatic Sea define distinct structural belts which are related to different tectono-stratigraphic units.

The most important oil and gas accumulation are found in the Ionian and Sazani zones and in the Periadriatic Depression which extends into the Adriatic off-shore. Structuration of the Ionian and Sazani zones occurred during the late- and neo-tectonic phases. The carbonate-dominated Late Trias-

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sic to Late Cretaceous series of the Ionian, Kruja and Krasta-Cukali zones contains several rich to very rich source-rock intervals. In the Ionian zone, Late Cretaceous, Paleocene and Eocene carbonates and Oligocene flysch-type and Miocene molasse-type sandstones form the reservoirs of the main oil and gas accumulations. In the Periadriatic Depression, Tortonian-Pliocene Molasse-type clastics form the primary reservoirs.

INTRODUCTION

The Albanides form an integral part of the southern branch of the Mediterranean Alpine Orogen which extends from the Southern Alps, through the Julian Alps, the Dinarides and the Albanides into the Hellenic arc. The Albanides have since long been the subject of intense surface geological studies which are summarized in a voluminous literature (Aubouin, 1973; Aliaj, 1987; Dalipi, 1985; Kodra and Gjata, 1989; Melo, 1986; Ndoja, 1988; Papa and Kondo, 1968; Papa, 1981; Shallo et al., 1989; Valbona and Misha, 1987).

The Albanides are subdivided into an internal and an external zone (Fig. 1). The Albanian Internides are formed by the Mirdita ophiolite nappe which was derived from the oceanic Subpelagonian Trough. This very large ophiolite nappe forms the orogenic lid of the Albanides and overrides the essentially sedimentary Korabi and Gashi nappes. The Externides comprise the Krasta-Cukali and Kruja nappes, derived from the Pindic and Gavrovo zones, respectively, and the Ionian and Sazani zones. The Krasta-Cukali and Kruja nappes are thrusted over the Ionian system of thin skinned thrust sheets and folds which are detached from their basement at the level of Permo-Triassic salts. The latter borders the little deformed Adriatic foreland, corresponding to the Adriatic Platform (Figs. 2 and 3).

Sedimentary series involved in the Albanides range in age from Ordovician to Quaternary and record their evolution. Following the Variscan orogeny, the area of the future Albanides began to subside during Permo-Triassic times under a tensional regime which culminated in the Late Triassic opening of the oceanic Subpelagonian Trough and the Hellenid-Dinarid Ocean, also referred to as the Vardar Ocean. Sea-floor spreading terminated during the Late Jurassic when closure of the Vardar Ocean and the Subpelagonian Trough commenced at the onset of the Alpine orogenic cycle. In Albania, the Alpine orogeny spanned Late Jurassic to recent times and can be subdivided into four cycles. During the Late Jurassic-Early Cretaceous palaeotectonic cycle, the Subpelagonia Trough was closed and the ophiolitic Mirdita and the sedimentary Korabi nappes were emplaced on the passive margin of the Adriatic plate. This was accompanied by the development of a first flexural foreland basin. During the Mid-Cretaceous to Eocene maintectonic cycle, the Pindos zone was incorporated into the orogen, forming the westward advancing Krasta-Cukali and Kruja nappes; during this time the Ionian zone was incorporated in the foreland basin. During the Oligocene to Miocene late-tectonic phase, the Ionian zone was deformed and during the Plio-Pleistocene neo-tectonic cycle, the most external peri-Adriatic foreland Basin was compressionally deformed; at the same time tensional Neogene basins subsided on the Mirdita nappe (Fig. 2).

In recent years, geophysical data have been increasingly and successfully applied in an effort to unravel the structural configuration of the Albanides and to establishing the relationship between their different tectono-stratigraphic units. Our analysis of the Albanides and their extension into the Adriatic Sea integrates surface geological observations, well data and the results of seismological, refraction- and reflection-seismic, gravity, magnetic and geoelectric surveys. (Aliaj, 1998; Arapi, 1982; Langora et al., 1983; Lubonja et al., 1977; Nishani, 1985; Sulstarova, 1987).

CRUSTAL CONFIGURATION

Refraction, gravity and magnetic data indicate that the thickness of the crust increases from about 30 km in the central parts of the Adriatic Sea and

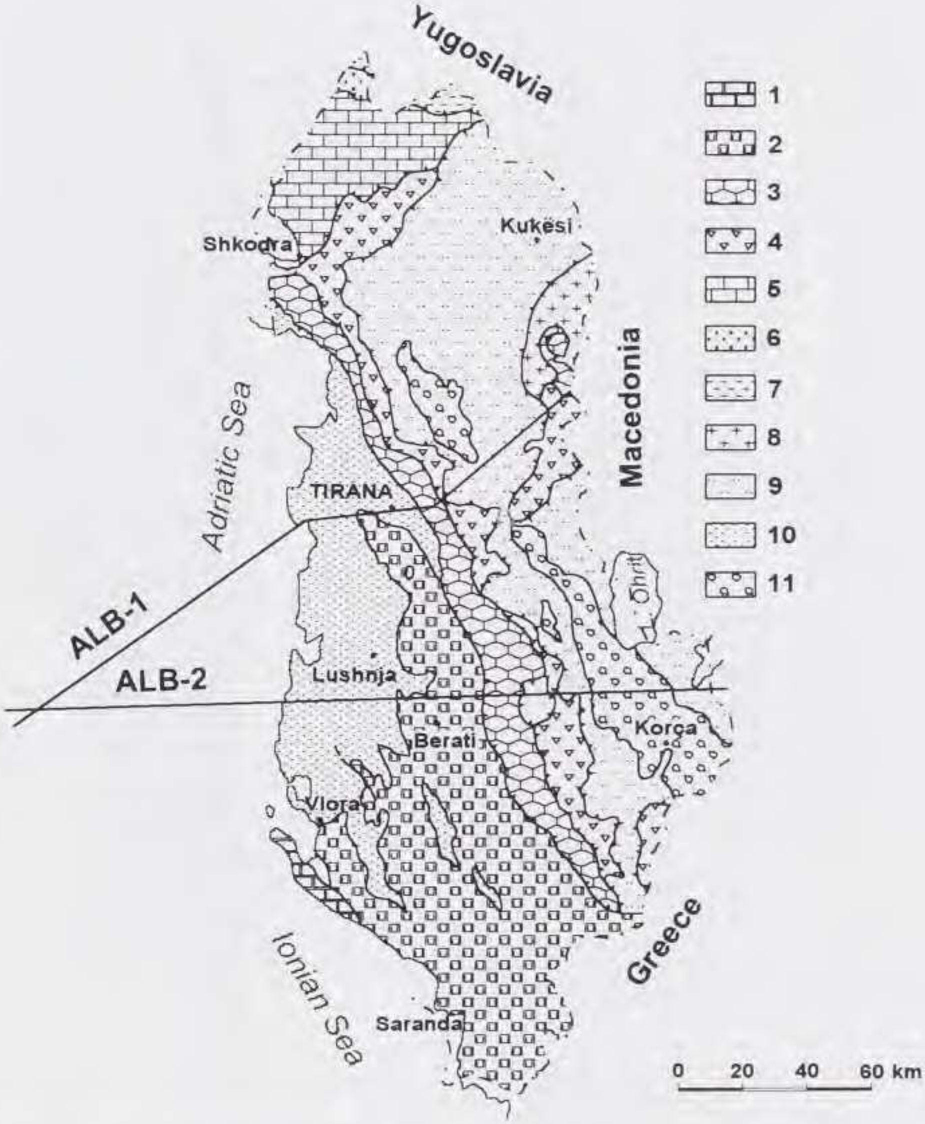

FIG. 1. Schematic tectonic map of Albania. Tectonic Zones: 1) Sazani, 2) Ionian, 3) Kruja, 4) Krasta-Cukali, 5) Alps, 6) Vermoshi, 7) Gashi, 8) Korabi, 9) Mirdita, 10) Periadriatic Depression, 11) Neogene depressions on Mirdita nappe. ALB-1 and ALB-2 locations of transects given in Figs. 2 and 3.

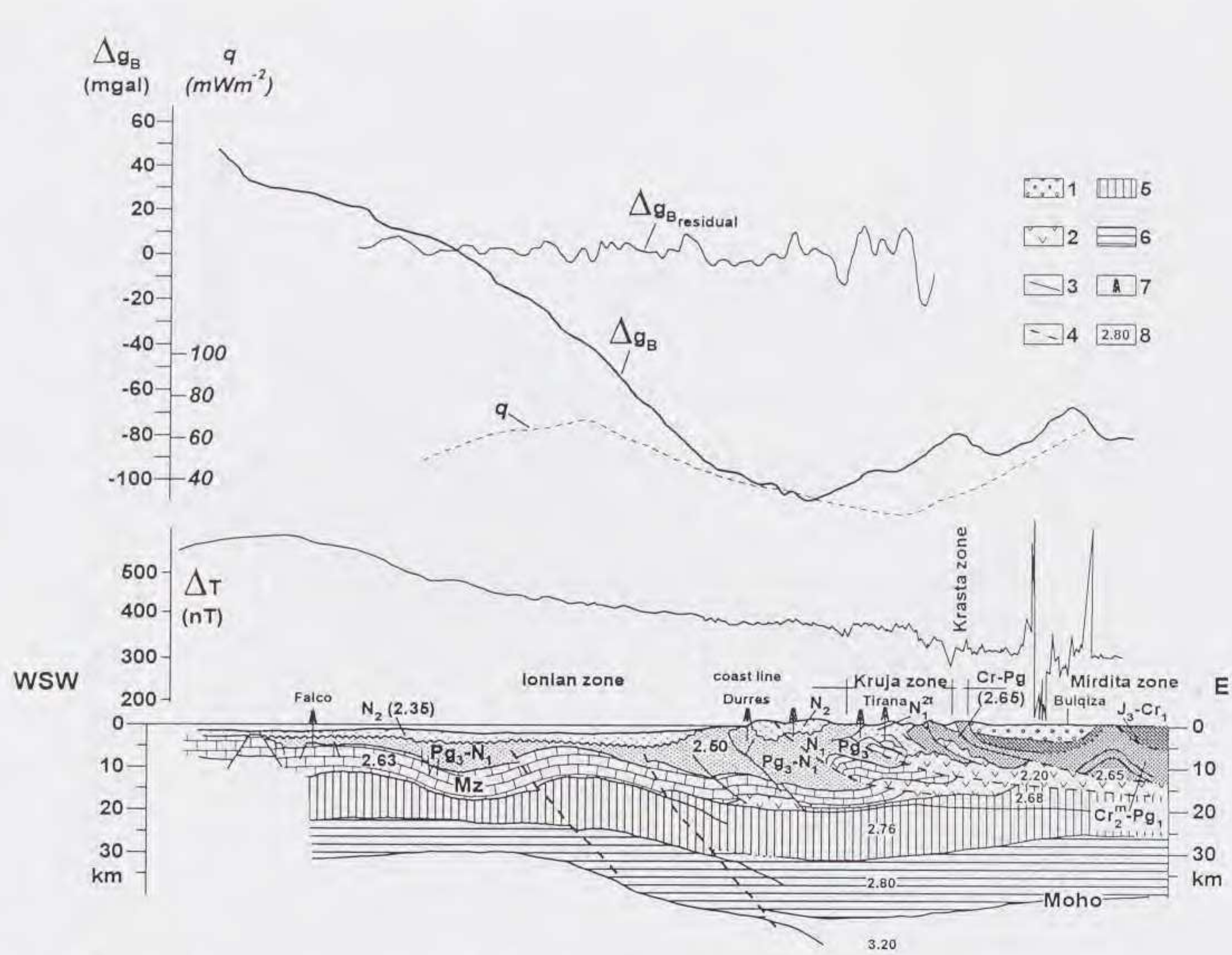

FIG. 2. Geological-geophysical transect ALB-1 through north-central Albania. For location see Fig. 1.
N-Neogene, Pg-Paleogene, Cr-Cretaceous, J-Jurassic, MZ-Mesozoic.
1) ultrabasic rocks, 2) salt, 3) faults, 4) crustal fractures, 5) upper crust, 6) lower crust, 7) upper mantle, 8) deep wells, 9) density g/cm^3.

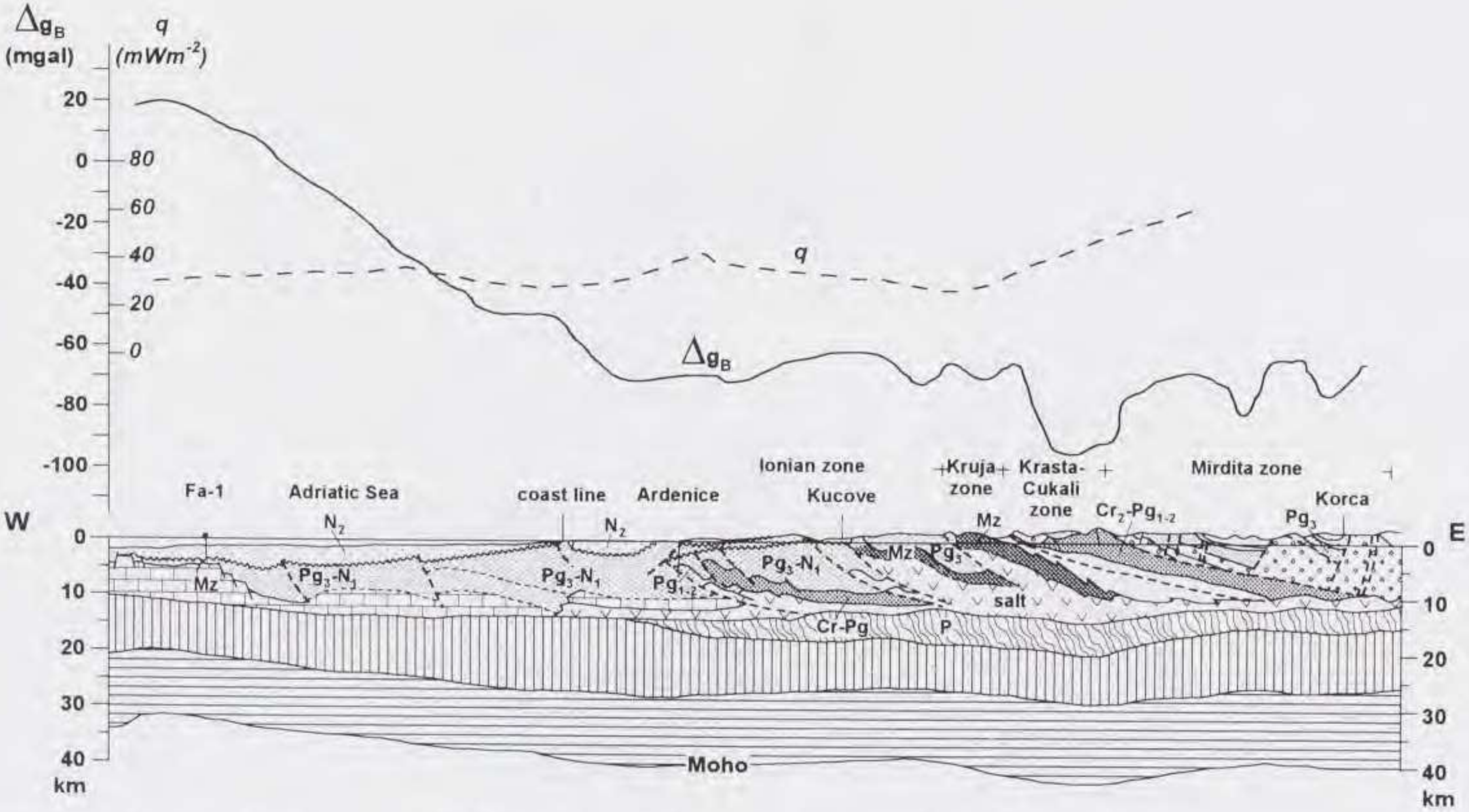

FIG. 3. Geological-geophysical transect ALB-2 through central Albania. For location see fig 1. Same legend as Fig. 2.

the Ionian zone to 43 to 52 km under the Albanian Internides (Figs. 2 to 4). Maximum crustal thicknesses are observed in the northern parts of Albania. Sediments attain thicknesses of minimum 12 km in coastal areas, increase to 13-14 km in northwestern Albania and up to 15-17 km in the central parts of Albania. In the southern coastal area the top of the basement is located at a depth of about 12 km and descends to 17 km in northern Greece.

The third order Bouguer gravity map (Fig. 5) shows the presence of a broad positive anomaly in the southern coastal area which is separated by a discontinuous negative trend from the sharp positive anomaly that is associated with the front of the ophiolitic Mirdita nappes. Refraction data confirm that the coastal positive Vlora anomaly coincides with a relatively shallow Moho whereas gravity minima correlate with greater crustal thicknesses. The configuration of these gravity anomalies suggests that the crust is subdivided into several blocks, varying in crustal thickness, which are separated by a system of deep reaching fracture zones (Fig. 5).

The northwestern positive gravity anomaly of the Shkodra area, which trends towards the Mirdita zone, suggests that the crust thickens to the North under the Albanian Alps as well as to the South in the Durresi area. The negative Durresi-Tirana-Elbasani and Permety anomalies, which are indicative of greater crustal thicknesses, are partly separated by the Vlora-Berati negative anomaly, corresponding to thinner crust. This subdivision of the crust into blocks is partly also reflected by the pattern of magnetic anomalies (Fig. 6). In the southern Adriatic Sea, the crust is characterized by a more uniform thickness of about 30 km (Fig. 2; Morreli et al., 1969; Montanari, 1989; Rigo and Caprarelli, 1980; Cadet et al., 1980).

Refraction- and reflection-seismic data, as well as gravity models and geoelectric soundings, suggest that the entire Albanides are underlain by an autochthonous continental basement complex which dips gently to the East (figs. 2 and 3). However, granitic basement is apparently involved in the Gashi zone of northernmost Albania (Fig. 1).

Although there is only limited evidence for involvement of the continental crust in this major thrust belt, seismological data indicate that deep transverse and longitudinal fractures transect the crust (figs 5 and 6; Aliaj, 1988; Grazhdani, 1987; Sulstarova, 1987; Bakiaj and Bega, 1986). Such crustal fractures, which are associated with earthquake epicentres, appear to coincide with the boundaries between the Krasta-Cukali and Kruja, the Kruja and Ionian and the Ionian and Sazani zones and occur also within the Ionian zone (figs. 1, 5 and 6). These fractures delimit blocks characterized by different crustal thickness, depth and gravity response. Although these fractures appear to influence the architecture of the Albanides, the age of their development is uncertain. However, earthquakes associated with them show that they are at present tectonically active. During the different orogenic cycles of the Albanides they may have controlled the subsidence pattern of the evolving foreland basin and guided the deformation of the sedimentary cover of the basement.

INTERNAL ALBANIDES

The Internides of the Albanides are dominated by the Mirdita nappe which occupies an up to 70 km wide belt in the western part of Albania. It rests in thrust contact on the Krasta-Cukali nappe, which reappears in erosional windows along the eastern border of Albania in the Peshkopia, Okshtuni and Gramozi areas. In the northern part of the Peshkopia window, the Korabi nappe appears beneath the Mirdita nappe. The Gashi nappe is restricted to northernmost Albania and appears to plunge southwards under the Mirdita nappe (Fig. 1). The Mirdita nappe is thought to be derived from the Subpelagonian Trough whereas the Korabi, Gashi and Krasta-Cukali nappes correspond to the Pindic margin of the Subpelagonian Trough.

Mirdita Zone

The Mirdita nappe consists of a basal Middle-Late Triassic ophiolite sequence which varies con-

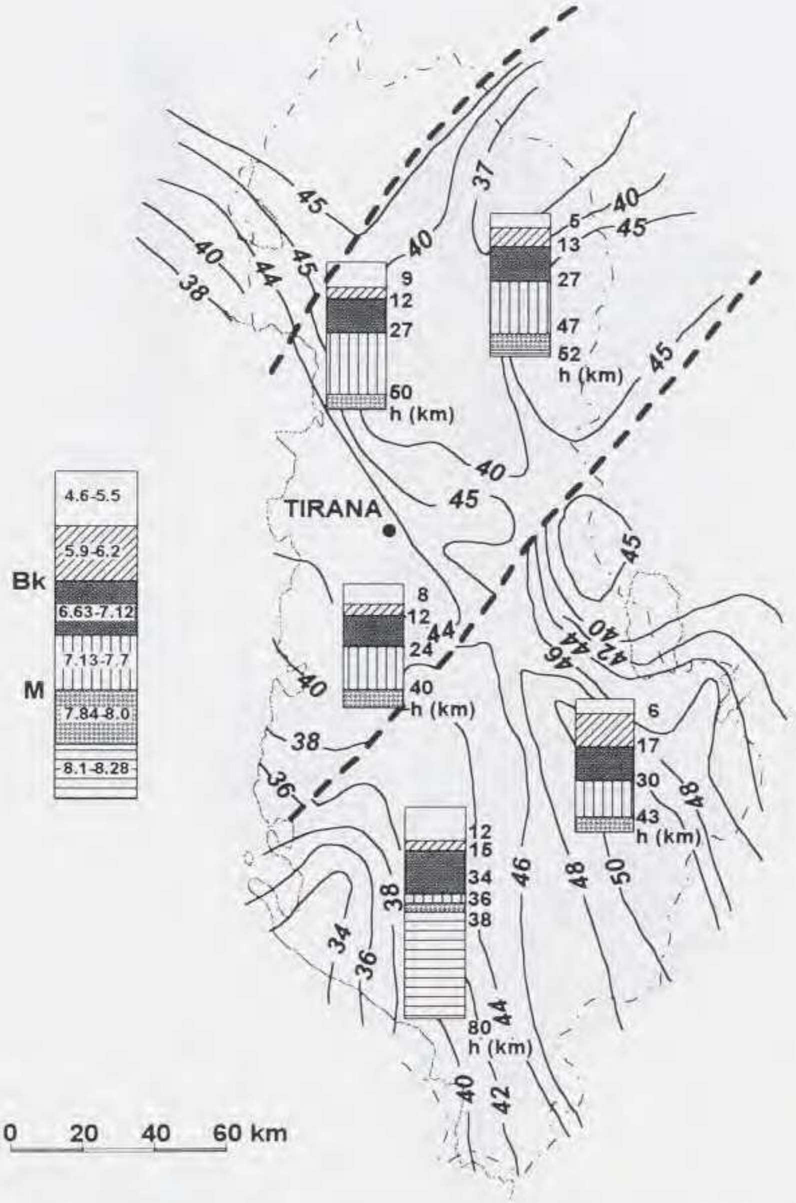

FIG. 4. Crustal thickness of Albania with selected velocity profiles. Contours depth to Moho in km. Bk: top crystalline basement, M: Moho.

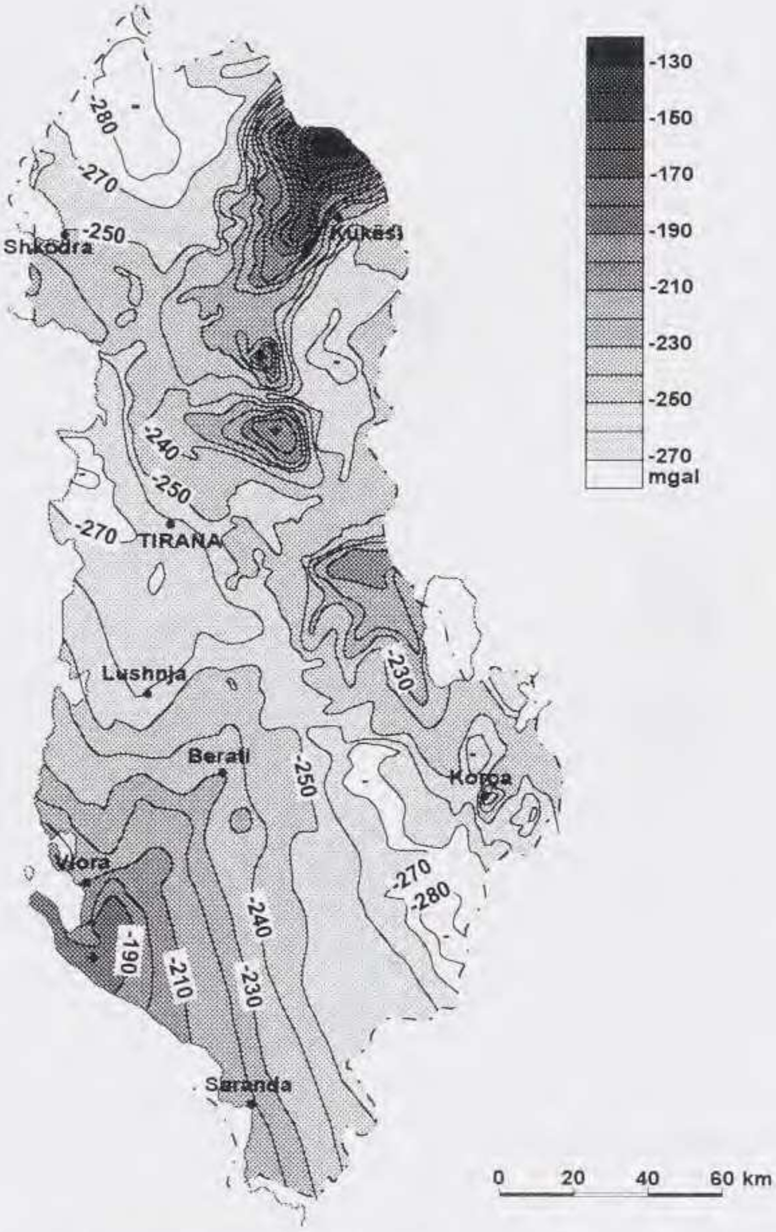

FIG. 5. Bouguer anomaly map of Albania.

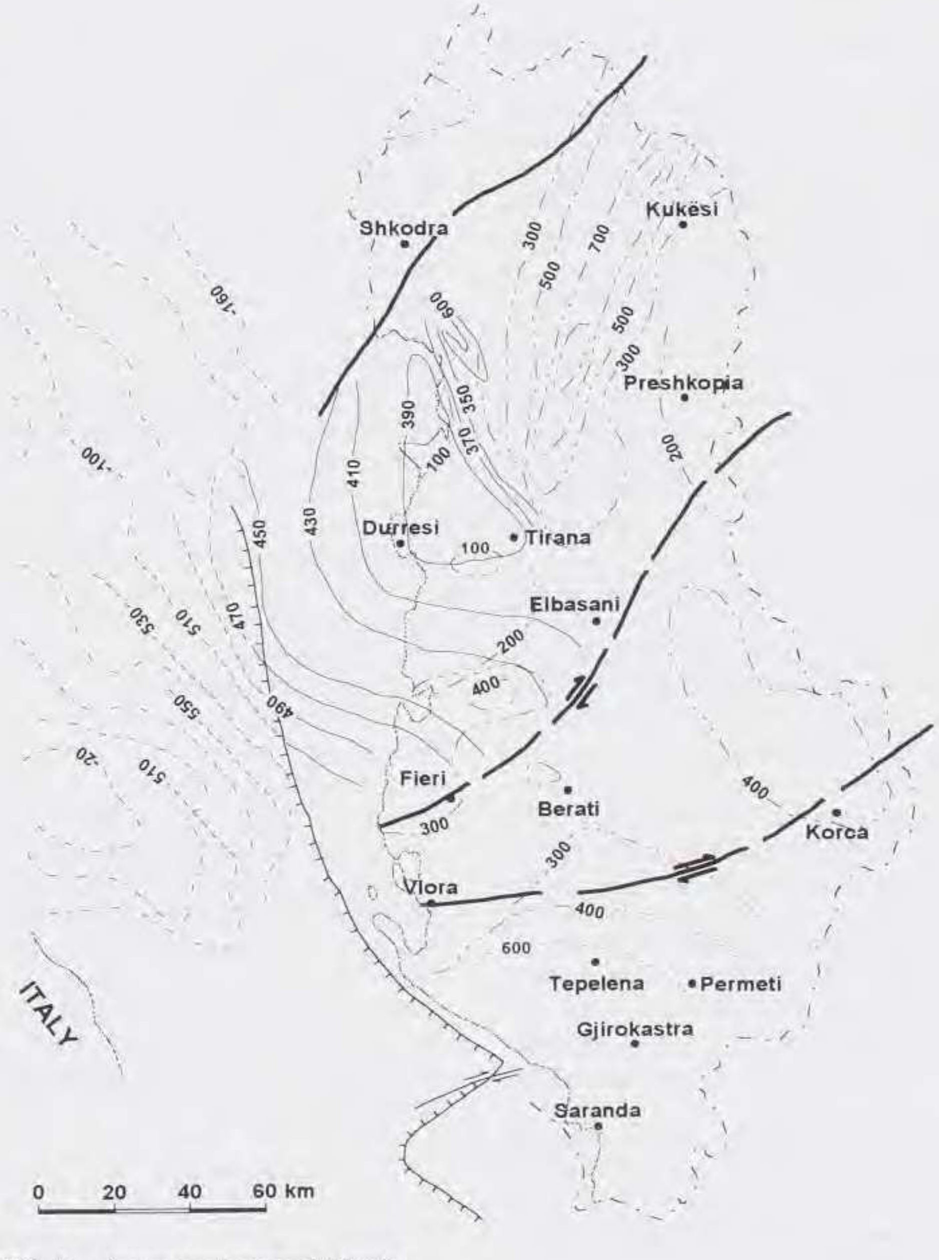

FIG. 6. Aeromagnetic map of Albania.

siderably in thickness and is overlain by Triassic and Jurassic carbonates (Fig. 7). In some areas the sedimentary cover of the ophiolites ranges upward into Late Jurassic (Tithonian) to Early Cretaceous (Berriasian) flysch. Eocene and younger continental clastics were deposited on top of the Mirdita nappe after its emplacement on the Adriatic foreland.

The Mirdita nappe was obducted on the western margin of the Adriatic plate during latest Jurassic. During the main- and late-tectonic phases, the Mirdita nappe was transported westwards on the back of progressively deforming more external sedimentary nappes as a passive orogenic lid which was internally only little deformed. The erosional Peshkopia, Okshtuni and Gramozi windows in the Mirdita nappe correspond to antiform features of the underlying Krasta-Cukali and Korabi nappes (Figs. 1 and 2). During the late-orogenic and neo-tectonic cycles, the extensional Burreli and Korca basins subsided on top of the Mirdita nappe; these form part of the Aegean-Pannonian collapse system and contain up to 5-6 km of Eocene to Late Miocene continental conglomerates and sands (Figs. 1 and 7).

The Mirdita ophiolites are interpreted as remnants of oceanic crustal material of the Subpelagonia Trough. Their basal parts consist of ultrabasic and gabbroic rocks. Ultrabasic rocks range from harzburgite to dunite and display different degrees of serpentinization. Basic rocks include troctolites, gabbro-olivinite, gabbro and gabbro-norite. Higher up in the sequence plagiogranites and quartzdiorites occur. The top part of the unit is formed by 5 km thick volcanic rocks. Gabbro-pegmatite and pyroxenite dykes occur in ultrabasic rocks, gabbro-pegmatites in gabbros and micro-tonalite, plagiogranite and porphyry dykes in plagiogranites and quartzdiorites. These dykes form phyllonitic complexes.

These ophiolitic rocks have average densities of 2610 kg/m^3 and an elevated magnetic susceptibility. Correspondingly, the Mirdita nappe gives rise to strong gravity as well as sharp magnetic anomalies tracking its outlines (Figs. 5 and 6). Figure 5 shows that the Mirdita nappe is characterized by several major gravity anomalies which are separated from each other. These anomalies, which partly also coincide with major magnetic anomalies, correlate with ultramafic massifs (Boltz, 1963; Lubonja et al., 1967).

The cross-sections given in Figs. 2 and 8 give examples of such anomalies. Deep boreholes drilled in the Bulqiza Massif, which is associated with a 48 mGal positive anomaly, have encountered at depths of 1000 to 1320 m ultramafic rocks with densities ranging between 2740 and 3310 kg/m^3 and a predominance of 3180 kg/m^3. Gravity modelling, applying this information, permitted to determined that the Mirdita allochthon attains a maximum thickness of about 6 km in the area of the Bulqiza Massif and overlays the sedimentary Krasta-Cukali nappe which surfaces to the west in front of the Mirdita nappe and to the east in the erosional Peshkopia and Okshtuni windows (Lubonja et al., 1967).

Surface geological data show that the northern parts of the Mirdita nappes are almost separated from their southern parts to the East of Tirana along the southwesterly trending erosional Peshkopia and Okshtuni windows in which the Krasta-Cukali zone outcrops in an antiform structure, involving Paleogene and Cretaceous flysch. These windows are readily recognized on the Bouguer map where they correspond to an elongate negative anomaly (Figs. 5 and 9).

The Mirdita nappe attains a maximum thickness of about 14 km in the ultramafic Kukesi massif in northeaster Albania from where it thins towards the West and Southeast to about 2 km. Away from ultramafic massifs, the magnitude of the Bouguer anomalies decreases rapidly (Fig. 10). However, a direct correlation between the Bouguer and magnetic anomalies cannot be established as ultramafic rocks have a highly variable magnetic susceptibility.which is generally greater than that of the encasing serpentinized ophiolitic rocks. In the southeastern part of Albania, the Mirdita nappe attains thicknesses of up to 10 km near the city of Korca (Fig. 3).

A reflection-seismic profile through the Neogene Burreli Basin, located to the northeast of Tirana, shows that it rests on non-reflective Mirdita ophiolites (Fig. 11). Seismic horizon 1 corresponds to the top of the Mirdita ophiolites and the base of the Neogene sedimentary fill of the Burreli basin. The base of the Mirdita ophiolite nappe corresponds to the strong horizon 2 reflector which gently rises from about 3.0 sec TWT at the eastern end

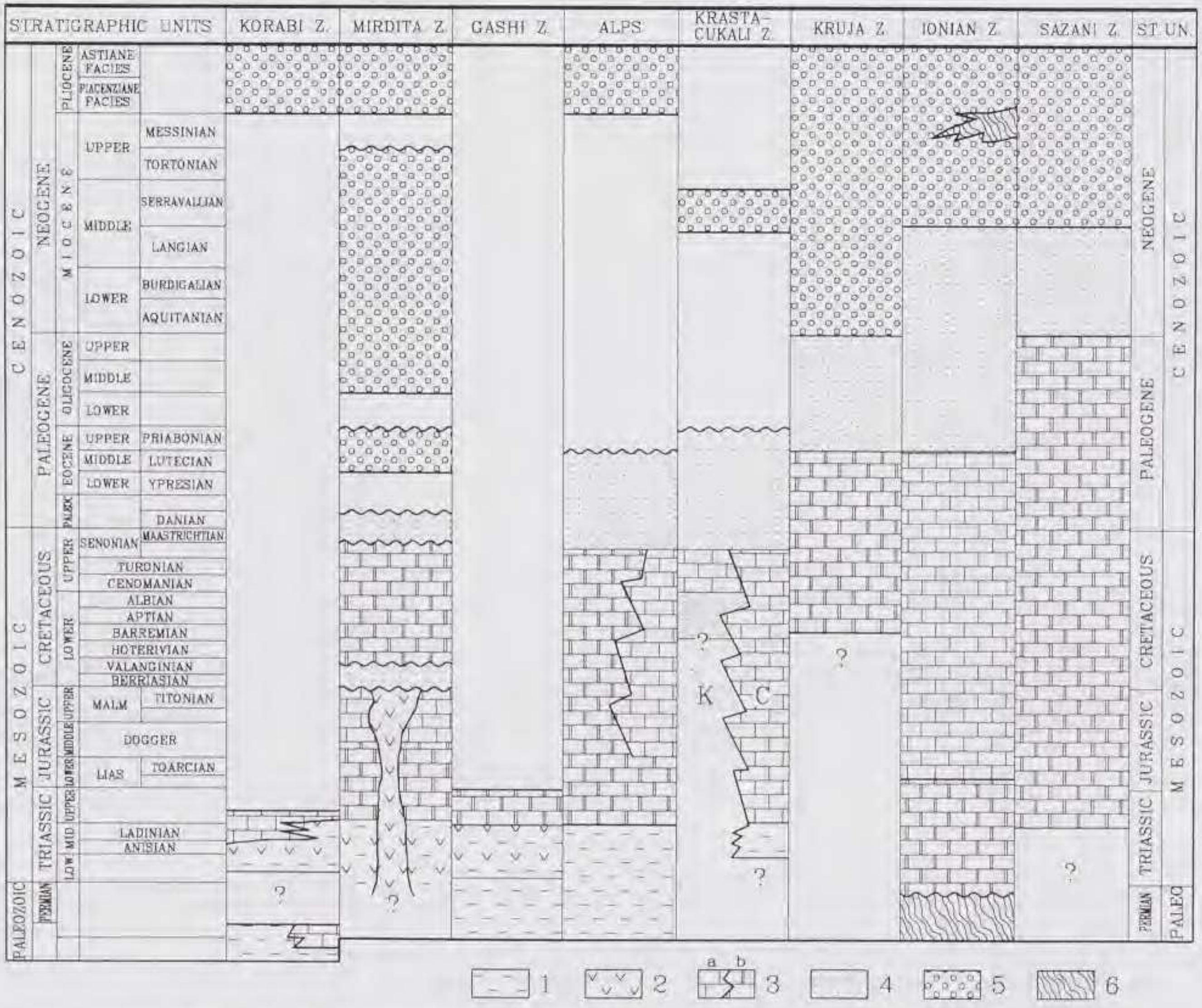

FIG. 7. Chrono- and lithostratigraphic chart of tectonic zones of Albanides.
1) lower terrigenous series, 2) diabase and spillite-keratophyr, 3) carbonates, a: pelagic, b: neritic, 4) flysch and pre-molasse, 5) molasse, 6) evaporites.

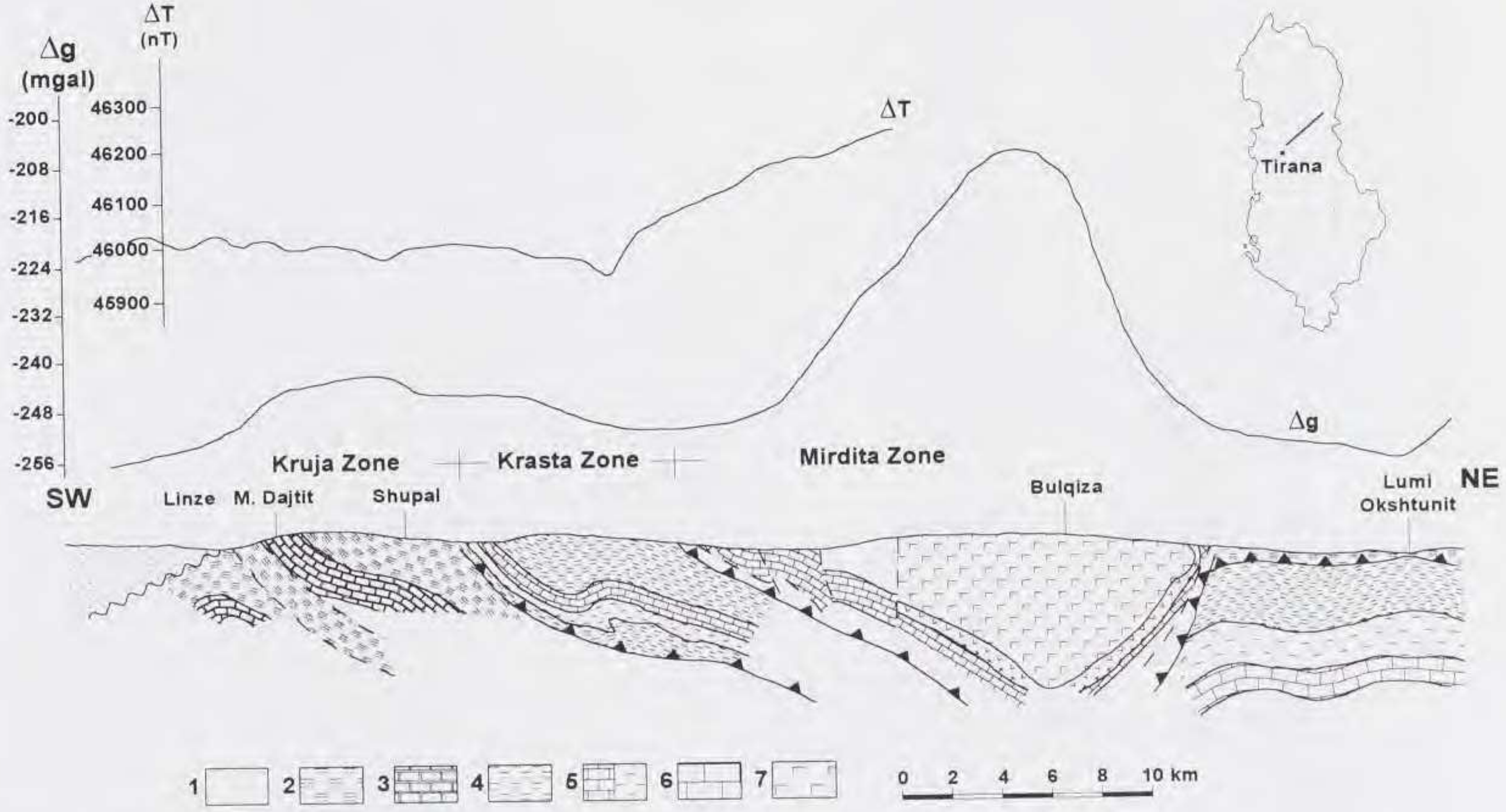

FIG. 8. Geological-geophysical cross-section through Kruja-Krasta and Mirdita zone, northeast of Tirana. Legend: 1) Tortonian, 2) Paleogene flysch, 3) Late Cretaceous-Eocene carbonates, 4) Tithonian-Early Cretaceous flysch, 5) Late Triassic-Early Jurassic carbonates and radiolarites, 6) Late Triassic carbonates, 7) Mirdita ophiolites.

of the profile to about 2.1 sec TWT at its western end. Beneath this sole-thrust reflector, subhorizontal events are attributed to the thrusted sedimentary sequences of the Krasta-Cukali and Kruja zone.

Based on reflection- and refraction-seismic data and gravity modelling, we postulate that autochthonous basement underlies the entire Internides of the Albanides.(Figs. 2 and 3). In view of this, the root of the Mirdita nappe is apparently not located within the territory of Albania and has to be sought further to the East. However, on-trend continuation of the Mirdita nappe into Greece leaves little doubt about its derivation from the Subpelagonian Trough.

Korabi Zone

The Korabi zone involves Silurian and Devonian schistose sandstones, conglomerates and metamorphic limestones and a Carboniferous flysch-type series which were deformed during the

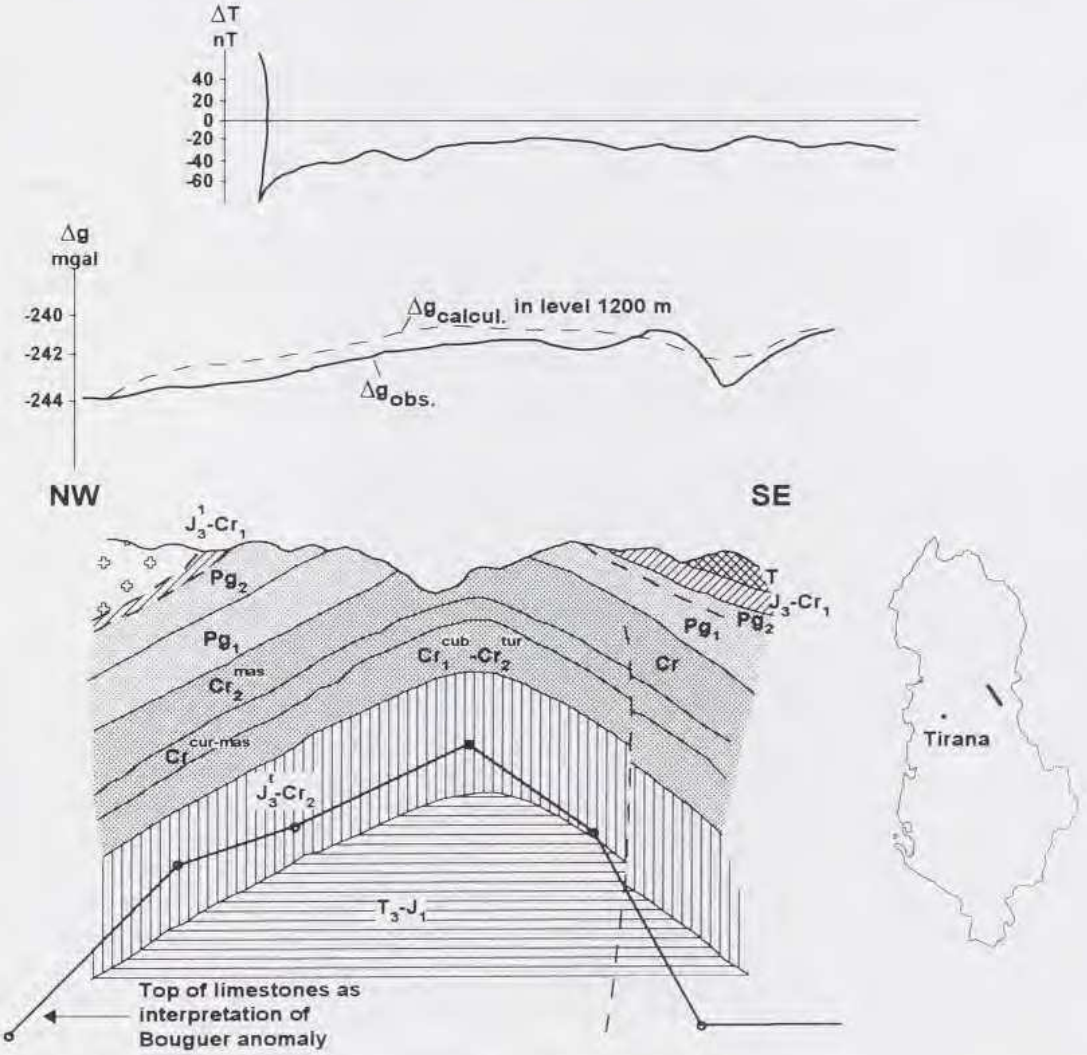

FIG. 9. Geological-geophysical cross-section through Paleogene and Cretaceous flysch exposures of Okshtun window. Abbreviations: T-Triassic, J-Jurassic, Cr-Cretaceous, Pg-Paleogene.

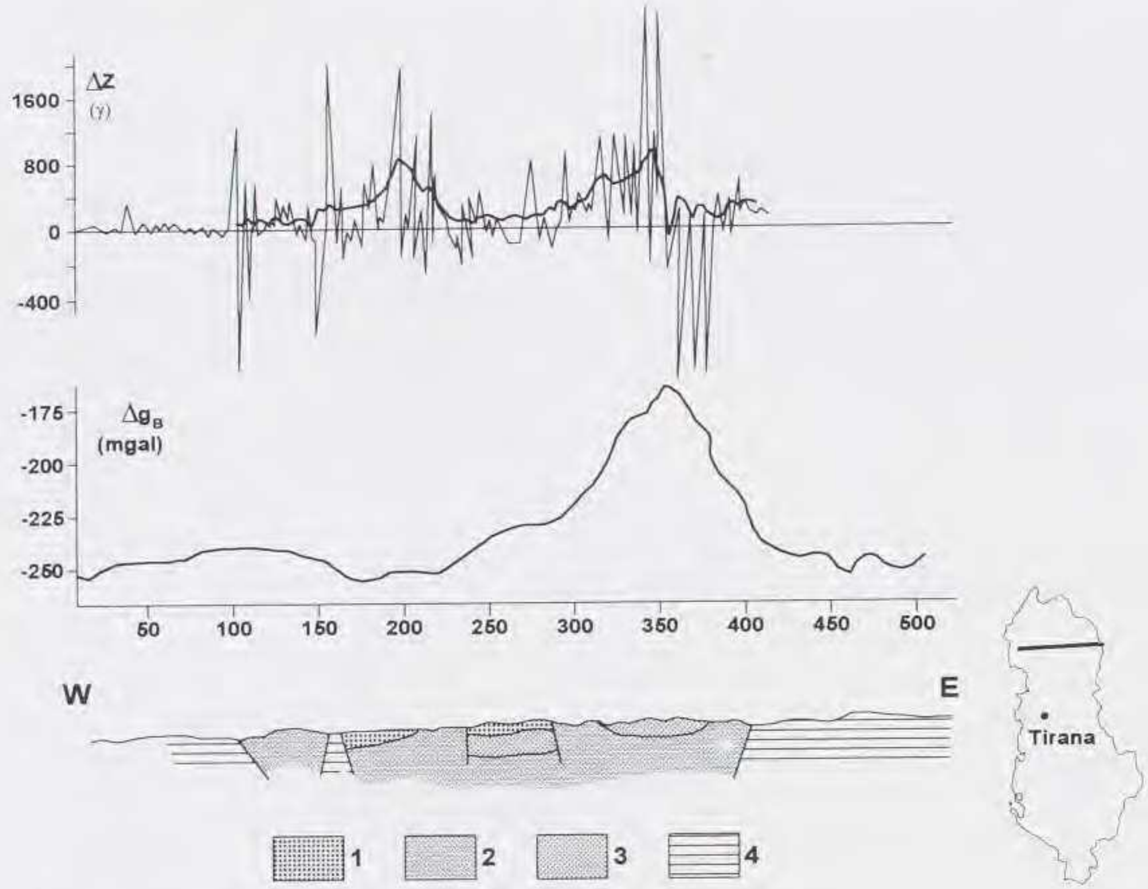

FIG. 10. Geological-geophysical cross-section through Mirdita nappe, Shkoder-Kukes area. 1) effusive rocks, 2) ultrabasic rocks, 3) gabbros, 4) sediments.

Variscan orogeny. These are overlain by Permian conglomerates, gypsum and anhydrites, Early and Middle Triassic clastics and Late Triassic carbonates, containing basic and alkaline volcanics and dykes. After a major hiatus, carbonate sedimentation resumed during the Senonian. Eocene series are developed in molasse facies (Fig. 7). Alpine deformation of the Korabi zone gave rise to the development of open folds and thrusted anticlines, partly cored by evaporites

The tectonic map of Albania, given in Fig. 1, shows that the Korabi nappe is confined to the northern parts of the Peshkopia window whereas in its southern parts the underlying Kruja and Krasta-Cukali nappes rise to the surface.

Gashi Zone

The Gashi zone correlates with the Durmitori zone of the Dinarides and occurs only in the northern-most parts of Albania. It consists of slightly metamorphosed clastic rocks and carbonates ranging in age from Palaeozoic to Mesozoic. Early and Middle Triassic clastics are overlain by Late Triassic carbonates.(Fig. 7) This series is overlain by a basement involving thrust sheet which, in turn, is covered by a sequence of metamorphosed intermediate and acidic and basic volcanics. The latter are attributed a Palaeozoic and Middle Triassic age. Field relationships indicate that the Gashi zone was overridden by the Mirdita nappe.

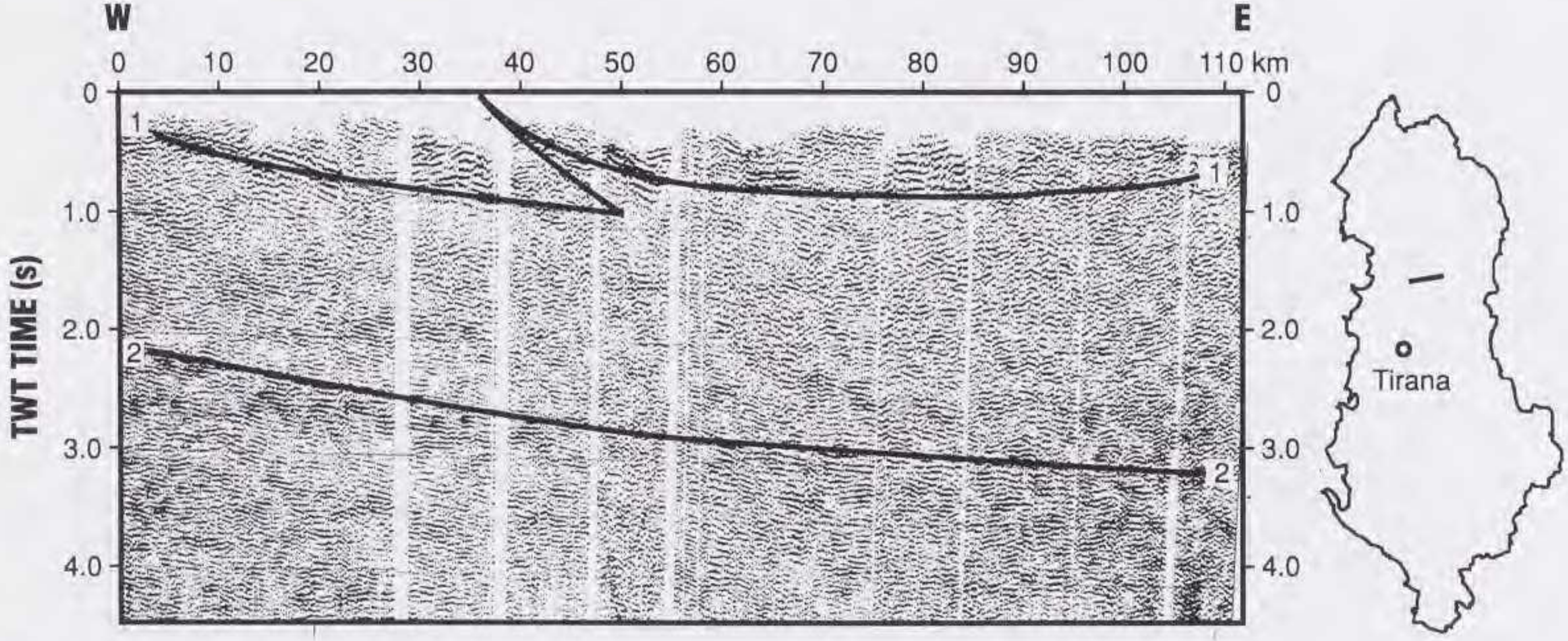

FIG. 11. Reflection-seismic profile through Neogene Burreli Depression (Nishani, 1985). Reflectors: 1) base Neogene sediments, top Mirdita ophiolites, 2) base Mirdita ophiolites.

EXTERNAL ALBANIDES

From East to West, the external elements of the Albanides consist of the Krasta-Cukali zone, which is assigned to the Pindic domain, the Kruja zone which corresponds to the Gavrovo-Dalmatian domain, and the Ionian zone and the Sazani zone which border the Adriatic foreland. In northern Albania, the Albanian Alps zone, which takes in an intermediate position between the Gashi and the Krasta-Cukali zones, is correlated with the Higher Karst zone of former Yugoslavia.

Geophysical data show that the External Albanides are underlain by a little deformed basement complex which deepens from 9-10 km under the Adriatic Sea to about 20 km near the Mirdita thrust front (Figs. 2 and 3). The top of the basement reaches a maximum depth of 12 km in the Durres-Tirana-Shengjini region which is characterized by gravity and magnetic minima (Figs. 5 and 6). Deep crustal fractures, corresponding to seismogenic zones, occur in the Ionian zone to the west of Durres (Fig. 2). The 15th April 1979 earthquake, which had a magnitude of 7.2 on the Richter scale, was associated with the Durres fracture zone. Focal mechanisms show that it was of a compressional nature, suggesting that crustal-scale imbrications, as shown in Fig. 8, are at present tectonically active.

Albanian Alps Zone

In the Albanian Alps, Permian sandstones and conglomerates are the oldest rocks exposed. These are covered by Early and Middle Triassic clastics, interbedded with tuffs. Late Triassic series consist of limestones and dolomites (Fig. 7). Neritic, biogenic limestones containing chert intercalations were deposited during Jurassic and earliest Cretaceous times. Maastrichtian-Danian onset of flysch sedimentation documents the incorporation of the Alps zone into the Albanides foreland basin. Deposition of flysch persisted into Eocene times. The Permian to earliest Cretaceous shelf series attain a thickness of 2300-3100 m whereas the flysch series ranges in thickness between 700 and 1200 m.

The Albanian Alps are characterized by a system of imbricate ramp anticlines which developed during the late-tectonic phase when the Alps zone was thrusted over the Krasta-Cukali zone (Fig. 12)

Krasta-Cukali Zone

The Krasta-Cukali zone correlates with the Pindic zone of Greece. It takes in an intermediate position between the Internides and the Externides of the Albanides and can be subdivided into the northern Cukali and the more internal Krasta zones.

The **Cukali sub-zone** involves Middle Triassic clastics and volcanic flows, Early Triassic to Cretaceous carbonates and includes latest Jurassic radiolarites. Flysch sedimentation commenced during the Maastrichtian and persisted into the Eocene (Fig. 7).

The Cukali zone is characterized by large thrusted anticlines which are overridden by the Mirdita and the Alps nappes. The contact between the Cukali and the underlying Kruja zone is marked by a major thrust fault. The schematic cross-section given in Fig. 12, crosses the southern parts of the Alps, the Cukali zone and its thrust contact with the Mirdita nappe. The gravity anomalies associated with the Alps and the Mirdita nappe are presumably the effect of the great thickness and density of Mesozoic carbonates and the ophiolites, respectively. On the other hand, the systematic gravity gradient across the Cukali zone could be either due to neo-tectonic enveloping of Mirdita ophiolites by the Cukali thrust sheets, or the involvement of a considerable thickness of high density Palaeozoic rocks in the Cukali thrust sheet.

The **Krasta sub-zone** extends as narrow belt from Shkodra to Leskovik (Fig. 1). In this zone Late Jurassic to Albian flysch, Maastrichtian carbonates and Late Maastrichtian to Eocene flysch are exposed (Figs. 7 and 8). On the other hand, flysch prevails in the Cretaceous to Paleogene series of the Okshtuni-Peshkopia window which transects the Mirdita nappe. Geoelectric surveys

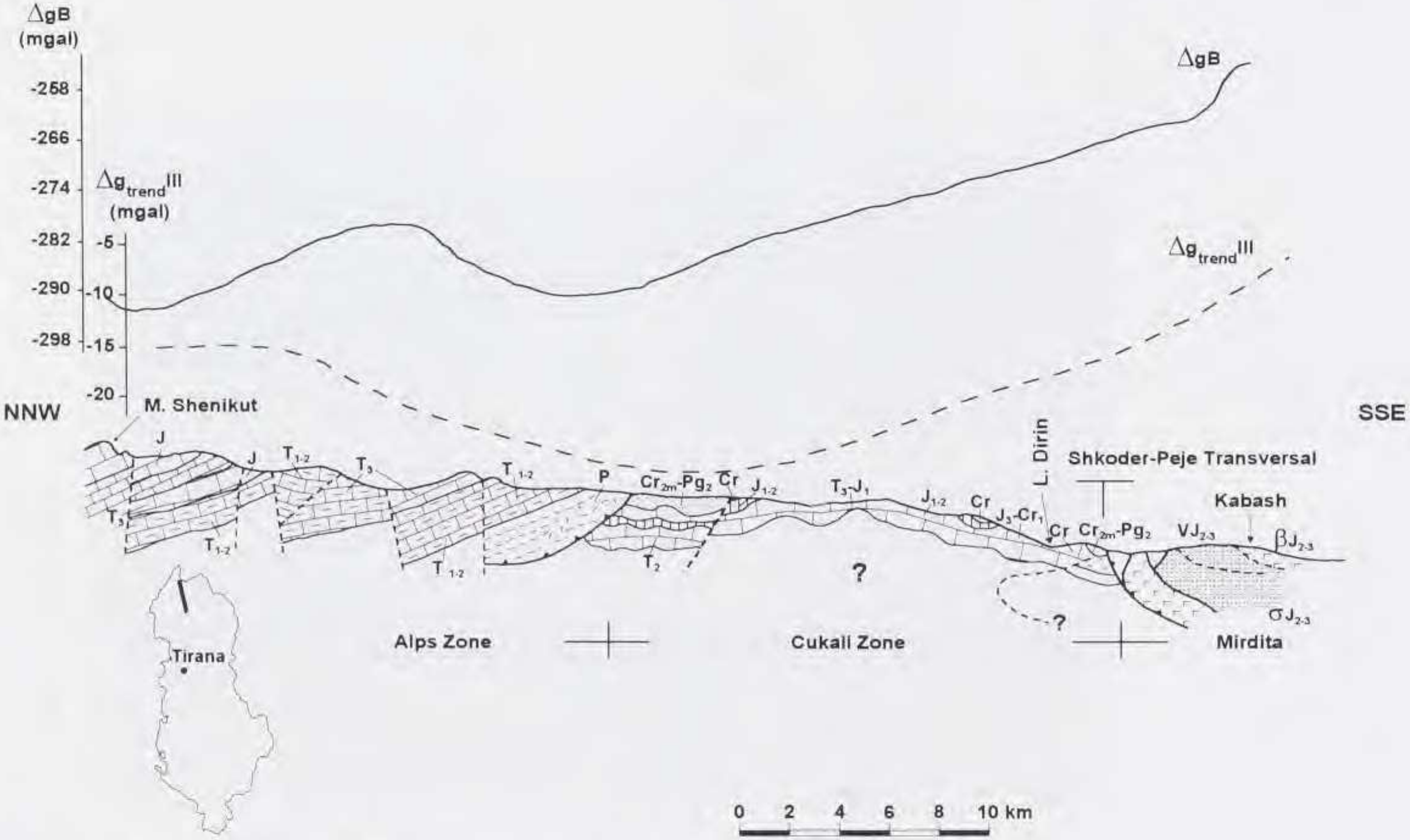

FIG. 12. Schematic geological-geophysical cross-section through Alps, Cukali and Mirdita zone, Northern Albania. Abbreviations: P-Permian, T-Triassic, J-Jurassic, Cr-Cretaceous, Pg-Paleogene.

indicate that the total flysch package has a thickness of 2000-2500 m. Although not exposed, gravity data suggest that the Mid-Cretaceous flysch is underlain by Triassic to Late Jurassic carbonates (Fig. 9). A deep well, drilled on the Okshtun structure, confirming this concept, could open new areas for oil and gas exploration.

Kruja Zone

The Kruja zone forms the prolongation of the Dalmatian zone of former Yugoslavia and links up to the South with the Gavrovo zone of Greece.

This zone is characterized by 1500 m thick Cretaceous to Middle Eocene neritic carbonates and 5 km of Late Eocene to Oligocene flysch (Fig. 7). Main deformations occurred during Mid-Oligocene to early Mid-Miocene times. Locally a Tortonian series, developed in a continental sand facies, rests unconformably on a variety of older strata (Fig. 8).

According to a reflection-seismic profile recorded across the Kruja zone in the area of Tirana (Fig. 13), two distinct, sub-parallel reflectors are observed at depths between 1.8-2.2 sec. TWT (horizon 2) and 2.9-3.3 sec TWT (horizon 3). Horizon 2 was identified as the top of the carbonates. The nature of horizon 3 is still uncertain but could correspond to the base of the Mesozoic carbonates and the top Permo-Triassic salts. Alternatively these reflectors could be related to the sole thrust of the Kruja zone and the top of a deeper, more external tectonic unit, involving a thick flysch package and basal carbonates. This could open up yet an other hydrocarbon play, requiring, however, the acquisition of new reflection-seismic profiles with better resolution than hitherto available.

Ionian Zone

The Ionian zone of Albania is the equivalent of the Ionian zone of Greece. It occupies a large part of the Albanian Externides and corresponds to a thin-skinned fold and thrust belt which is detached from the basement at the level of Permo-Triassic evaporites (Figs. 3 and 14). Late Triassic to Early Jurassic neritic limestones and dolomites are covered by Middle Jurassic to Eocene pelagic limestones containing cherts (Fig. 7). The thickness of these carbonates range between 2.5 and 4 km. Late Eocene to Aquitanian series are developed in flysch and flyschoid facies and attain thicknesses of 4 to 6.5 km. An angular unconformity at the base of the Burdigalian to Serravallian clay and marl series, truncates anticlinal structures and testifies to a first folding phase. Serravallian to Messinian sediments are developed in a molasse-type facies. Burdigalian to Messinian strata attain a thicknesses of up to 5 km.

The Ionian zone hosts 11 producing oil and gas fields (Fig. 17). These are reservoired in Late Cretaceous and Paleogene carbonates and in sands of the Eo-Oligocene flysch series. These accumulations are contained in structural, stratigraphic and combination traps.

Hydrocarbons show geochemical variations which are related to different source-rocks. Main source-rock intervals occur in the Late Triassic and Late Cretaceous carbonate series (Diamanti, 1992).

Sazani Zone

The Sazani zone corresponds to the most external unit of the Albanides and marks the transition to the Adriatic foreland platform. It is characterized by thick Cretaceous to Eocene limestones and dolomites (Fig. 7). Burdigalian to Tortonian marls transgress over an erosional surface and attain thicknesses of up to 5000 m (Fig. 15). Flexural subsidence of this part of the foreland basin was accompanied by Neogene normal faulting. Tortonian and older strata are involved in frontal thrusted structures.

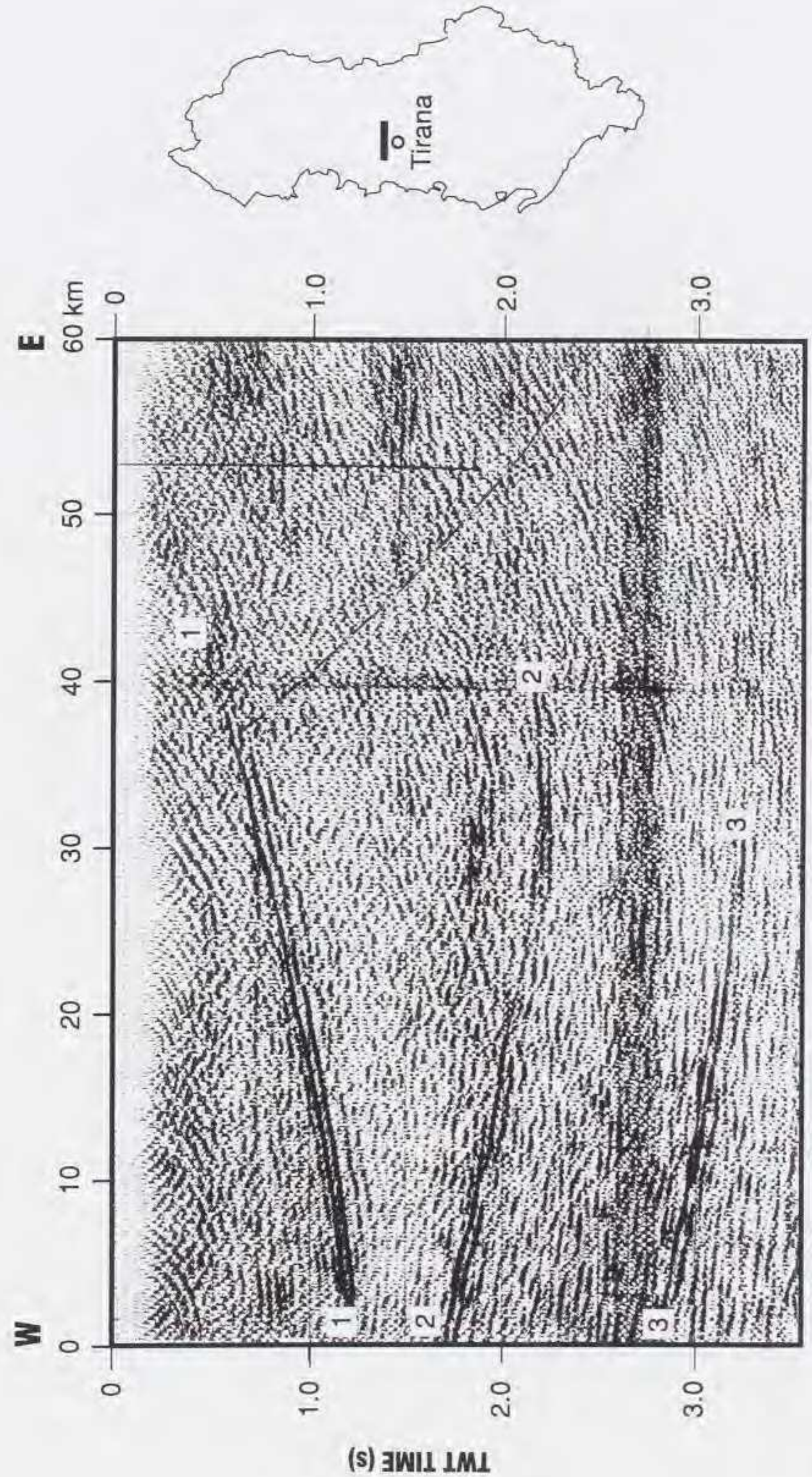

FIG. 13. Reflection-seismic line through Neogene depression near Tirana (Nishani, 1985). Reflectors: 1) base Tortonian, 2) top carbonates, 3) uncertain deep level.

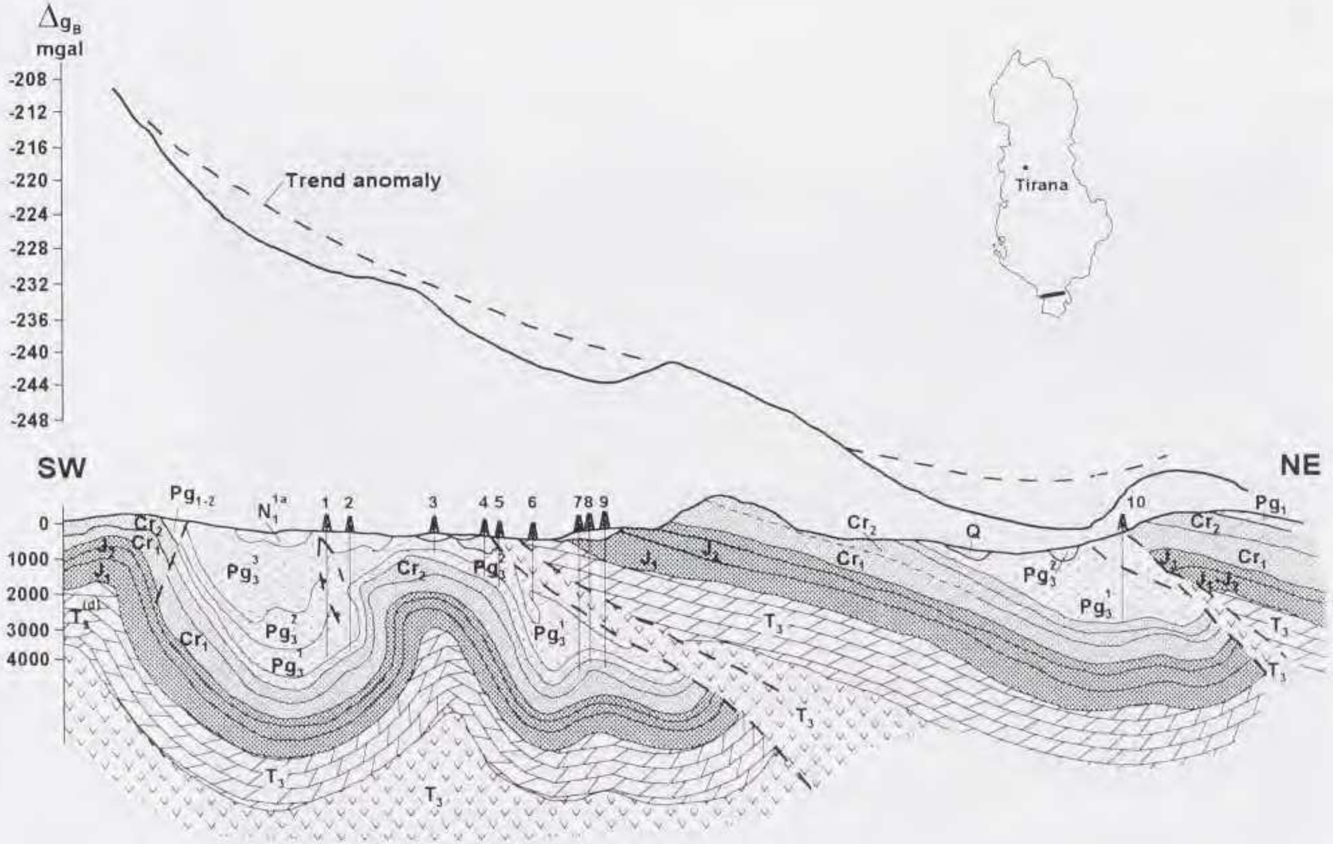

FIG. 14. Geological-geophysical cross-section through Ionian zone, Saranda-Gjirokastra area, Southern Albania. Abbreviations: T_3-Late Triassic evaporites and dolomites, J-Jurassic, Cr-Cretaceous, Pg-Paleogene, N-Neogene, Q-Quaternary.

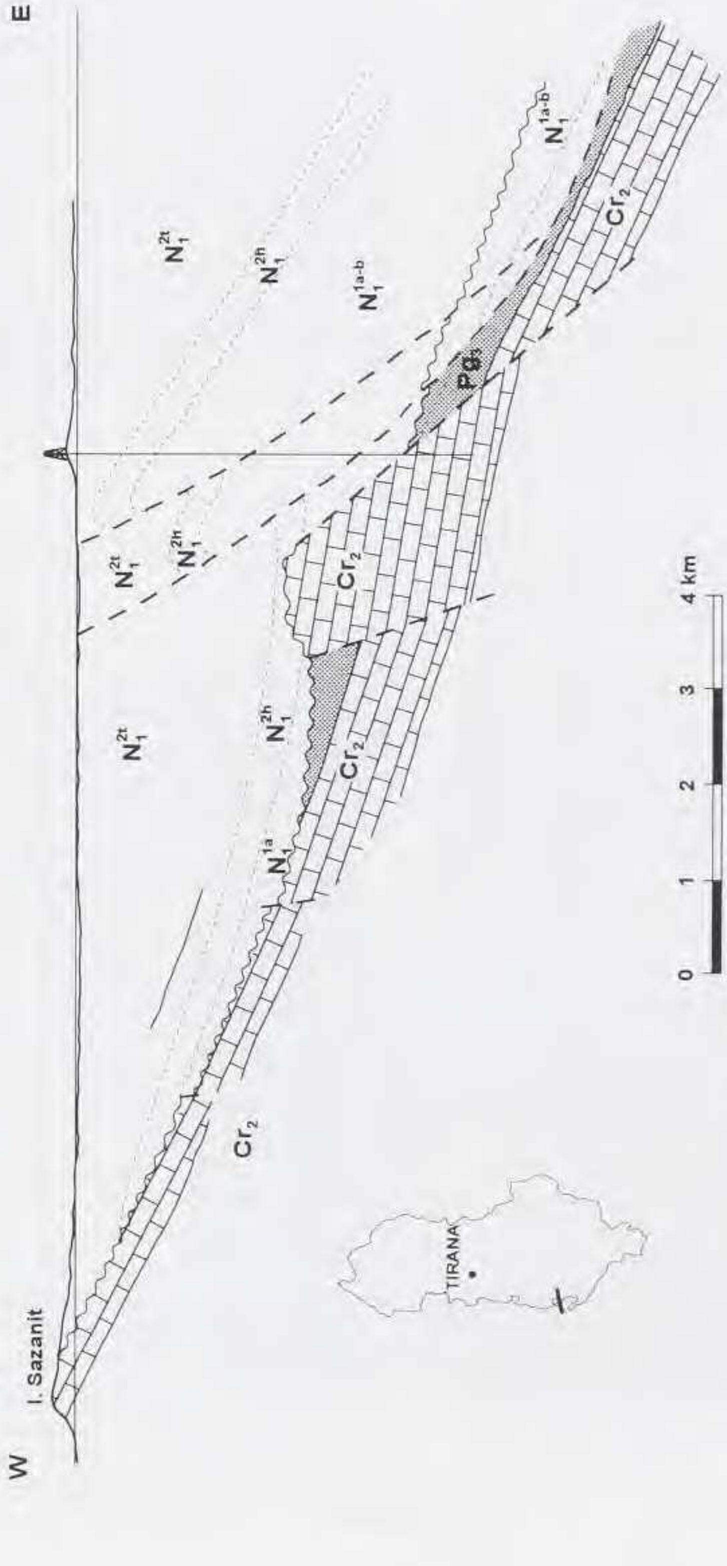

FIG. 15. Structural cross-section through Sazani Zone in Vlora Region. Abbreviations: Cr_2-Late Cretaceous, Pg_3-Oligocene, $N_1^{2a\text{-}b}$-Aquitanian-Burdigalian, N_1^{2h+t}-Helvetian and Tortonian.

PERIADRIATIC DEPRESSION

The Periadriatic depression is filled with continental and deltaic Miocene and Pliocene series which prograde into the Adriatic Sea and are covered by Quaternary deposits.

On-shore, the proximal parts of the Periadriatic Depression cover the northeastern parts of the Sazani and Ionian zone and partly also the Kruja zone (Fig. 1). Tortonian sandstones and clays rest unconformably on deformed older strata and are themselves involved in compressional structures (Figs. 8 and 16). Pliocene clays, sandstones and conglomerates rest unconformably on Tortonian and older series and document a two-phase deformation history of this area.

Off-shore, the Neogene sedimentary wedge expands rapidly to some 5-7 km and rests in the central Adriatic on Oligocene flysch, attaining a thickness of 2-3 km, and on Cretaceous and Eocene carbonates; these series are involved in extensional fault blocks (Figs. 2 and 3). The latter give rise to local gravity and magnetic anomalies (Frasheri et al., 1969; Richeti, 1980; Rigo and Caprarelli, 1980). Geophysical data indicate that in the Adriatic the Neogene series are underlain by up to 6 km of Mesozoic strata, which, in analogy with drilling results from the Italian Apulia platform, consist of basal Triassic clastics and evaporites and Late Triassic to Eocene carbonates. Late Triassic series, deposited in depressions can have source-rock characteristics and can provide a hydrocarbon charge to such fault blocks (see Anelli et al., this volume). Away from the central parts of the Adriatic, compressional structures play an increasingly important role as the coast is approached. The occurrence of possibly crustal scale thrusted anticlinal features, as shown on Fig. 2, is indicated by the available geophysical data. Such features are characterized by positive gravity and negative magnetic anomalies, suggesting uplift of thick carbonate units. Such features are located on trend with the Sazani zone. A further uplift of the Mesozoic carbonates may occur in the Durres area; this feature is interpreted as a deep-seated ramp anticline which is detached from the basement at the level of Permo-Triassic evaporites.

In the on-shore parts of the Periadriatic Depression, so far eight commercial oil and gas fields have been discovered (Fig. 17) These are reservoired in the Neogene molasse series, which provide for stacked accumulations in structural and stratigraphic traps. At shallow depths, tar deposits and accumulations of biodegraded oils occur. At greater depths, undegraded oil accumulations with gas caps and gas/condensate accumulations with oil legs are present. Hydrocarbon generation and migration had commenced already during the deposition of the Tortonian series, that is prior to the Early Pliocene final structuration of the area. Multiple source-rock intervals, having a regional extent, are recognized (Fig. 18; Diamanti, 1992).

CONCLUSIONS

The Albanides are a typical, west-verging Alpine thrust belt, the internal parts of which are characterized by a stack of ophiolitic and sedimentary nappes whereas its external parts are formed by thin-skinned thrust sheets.

Geophysical data have greatly assisted in understanding the architecture of the Albanides. Gravity modelling indicates that the Mirdita ophiolite nappes attains thicknesses ranging between 2 to 14 km. Reflection seismic data confirm the nappe structure of the Albanian Internides and define the thrust front of the Ionian and Sazani zones towards the undeformed Adriatic foreland. Moreover, geophysical data indicate that the foreland crust extends essentially unbroken for at least 100 km from the thrust front of the Albanides under their internal nappes where its top is located at depths of about 20 km. Correspondingly, the Albanian sedimentary basin extends from the Adriatic Sea deep under the Externides and Internides of the Albanian orogen. Earthquakes indicate that neo-tectonic deformations include the compressional reactivation of crustal-scale fractures.

The onset of flysch deposition in the different tectono-stratigraphic zones of the Albanides and their foreland indicates that latest Jurassic-earliest Cretaceous obduction of the ophiolitic Mirdita

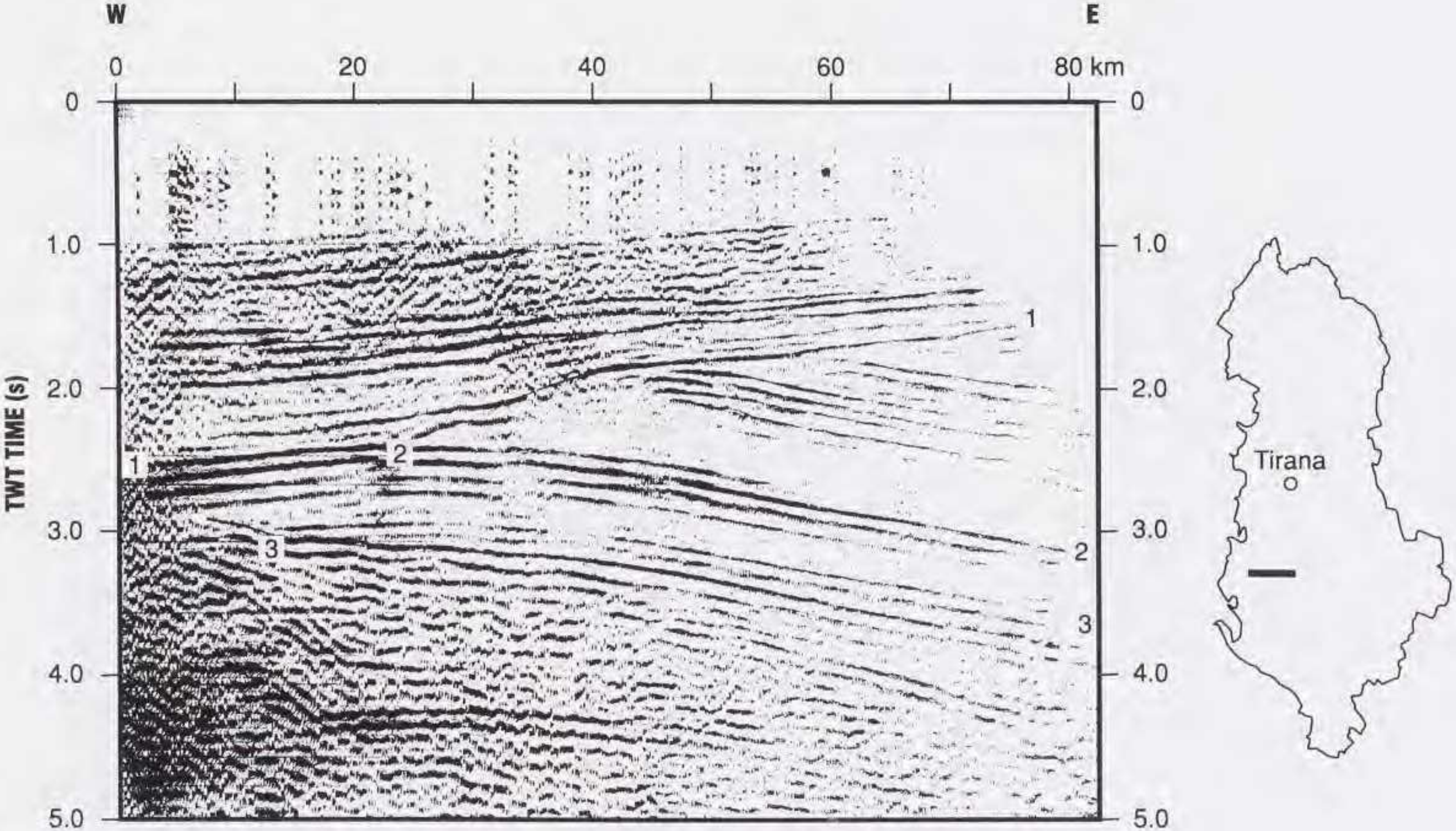

FIG. 16. Reflection-seismic profile through Periadriatic Depression, northwest of Berati. Reflectors: 1) base Tortonian unconformity, 2) top carbonates, 3) deep event.

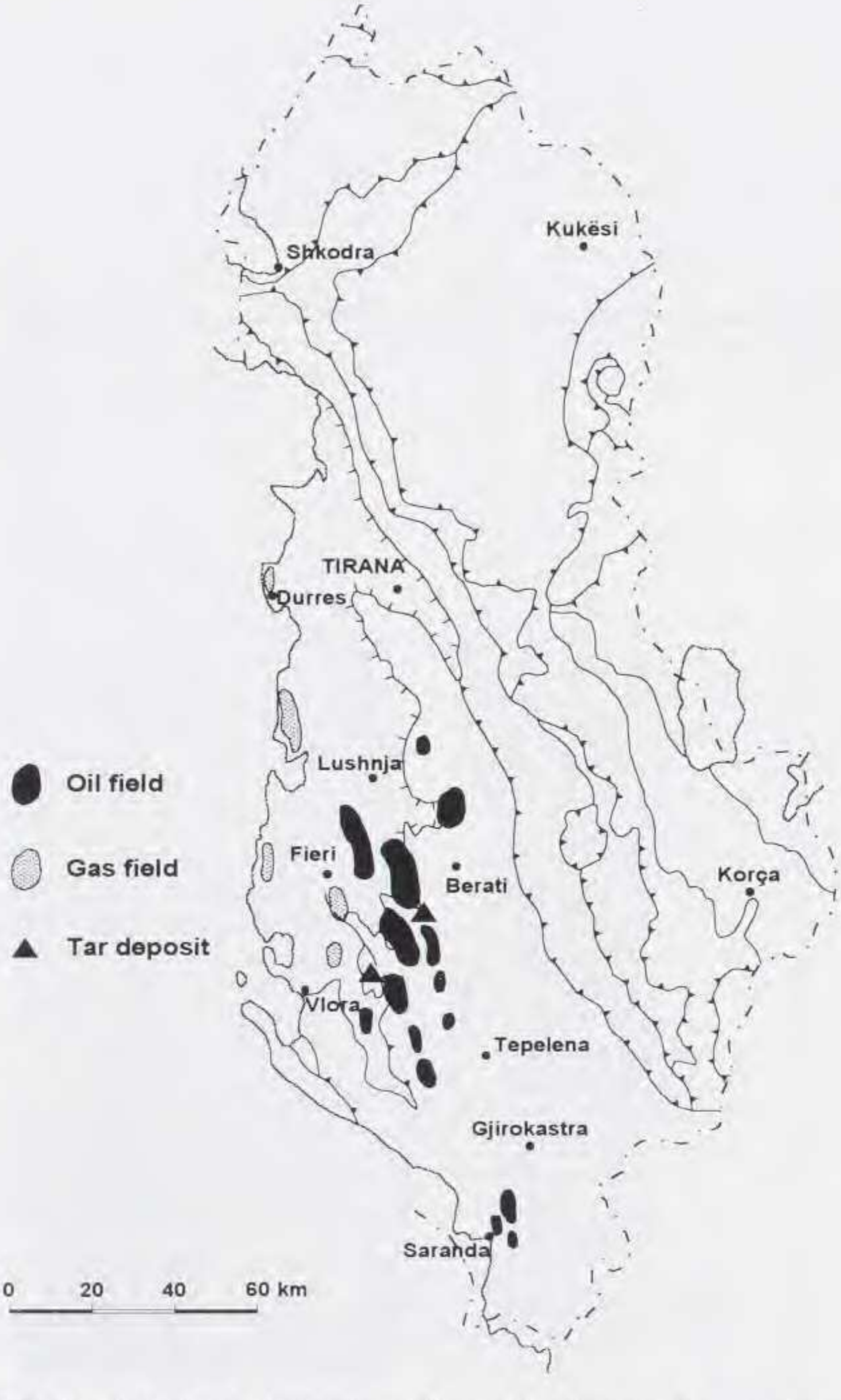

FIG. 17. Oil and gas fields of Albania. Tectonic boundaries are the same as in Fig. 1.

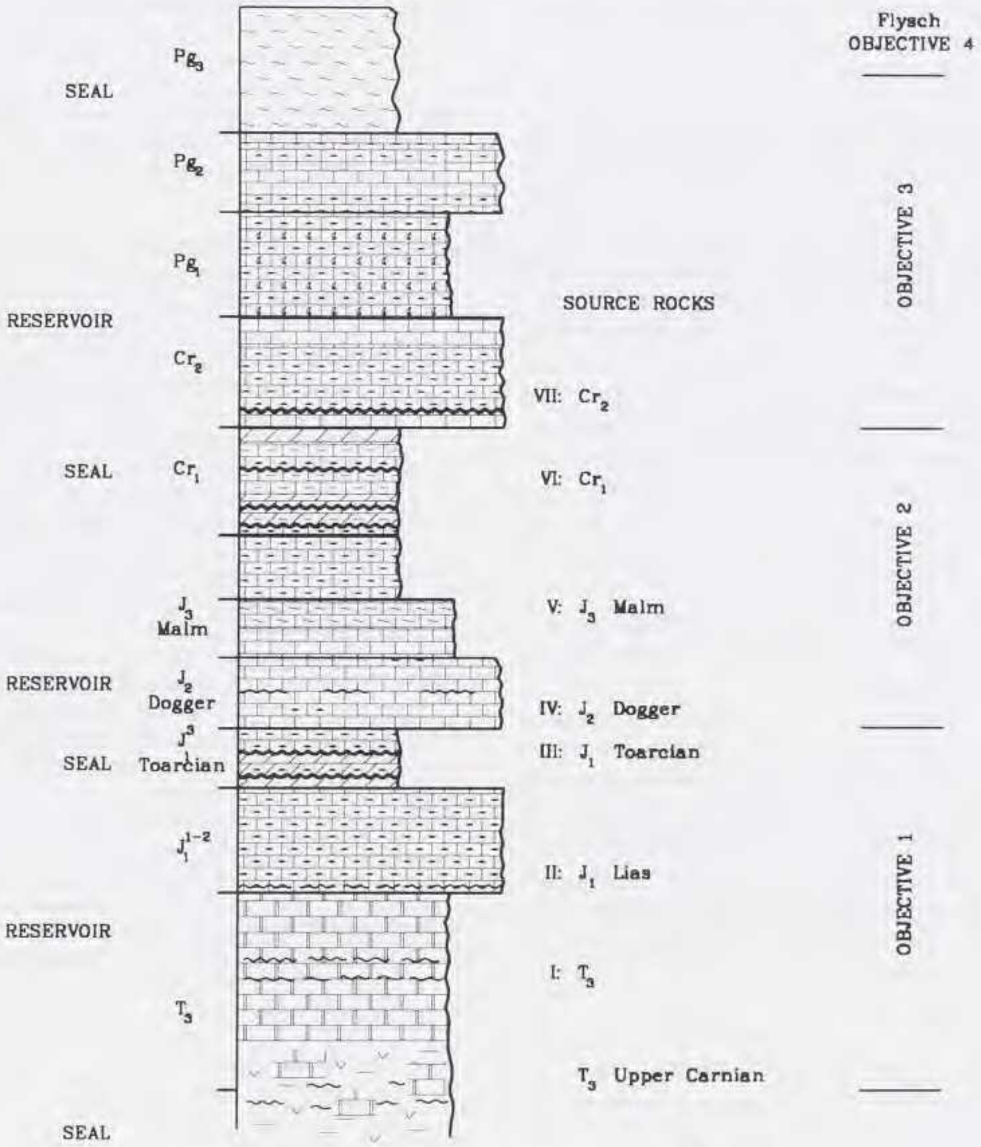

FIG. 18. Stratigraphic column showing position of main source-rocks in Albania.

nappe was accompanied by the development of a flexural foreland basin. During the Cretaceous to Neogene orogenic phases of the Albanides, progressively more external zones were incorporated into this foreland basin whereas more internal zones became involved in an orogenic stack of nappes. The main phase of nappe displacement occurred during the Paleogene when the Krasta-Cukali and Kruja nappes were emplaced. Neogene two-phase deformations characterize the Ionian zone and the Periadriatic Basin.

The thin-skinned thrusted and folded structures of the Ionian zone and the Periadriatic Basin host a number of oil and gas accumulations. Several source-rock intervals, having a high oil and gas generation potential, are recognized within the Mesozoic carbonate series. Multiple reservoir/seal pairs are associated with the Neogene molasse series which is the main producers in the Albanian Basin. Additional reservoirs are developed in the Mesozoic to Eocene carbonates. These are involved in folds, ramp anticlines and imbricate thrust sheets. Prospects in the Adriatic off-shore have a high priority since they are located in water depths of often less than 100 m.

The most important oil and gas accumulation are found in the Ionian and the Periadriatic Depression which extends into the Adriatic off-shore. Structuration of the Ionian and Sazani zones occurred during the late- and neo-tectonic phases. The carbonate-dominated Late Triassic to Late Cretaceous series of the Ionian, Kruja and Krasta-Cukali zones contains several rich to very rich source-rock intervals. In the Ionian zone, Late Cretaceous, Paleocene and Eocene carbonates and Oligocene flysch-type sandstones form the reservoirs of the main oil and gas accumulations. The Tortonian-Pliocene Molasse-type clastics of the Periadriatic Depression contain source-rocks and mainly stratigraphically trapped gas accumulations.

Established hydrocarbon accumulations are areally and depth-wise restricted. The great thickness of the sedimentary series, the occurrence of good quality source-rocks at several stratigraphic levels, the suitable relationship between source-rocks and reservoir/seal pairs and the structuration of the external zone of the Albanides provide excellent conditions for entrappment and preservation of major hydrocarbon accumulations, not only at shallow but also at greater depths. In view of the above, we conclude that the remaining hydrocarbon potential of the Albanian on-shore and off-shore is significant.

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